# 10. Discussion and conclusions

The main question addressed in this thesis was: what are the incentives for and against malaria control and elimination-related activities? This dissertation examines the question through both observation (of private actors engaged in malaria control at the levels of the firm, health programmes, and country) as well as direct inquiry (of malaria researchers and recipients of malaria control interventions).

## 10.1 Discussion

**The existence of incentives:**
At the organization level, ample incentives exist to engage directly in malaria control. The most clear example of the evidence of incentives is the fact that the Maragra vector control program was profitable even from a purely financial perspective (ie, not taking to account any benefits in human wellbeing). Additionally, there are direct and indirect economic benefits for firms in regards to public relations when they engage in malaria control, as evidenced by the presence of both foreign and domestic firms engaging in such activities despite not having a clear internal reckoning of their economic payoff.

At the individual level, uptake of and compliance with low-cost interventions appear high, as demonstrated in the Gambian bednet usage evaluation. This itself suggests that individuals are sufficiently incentivized to self-protect, thereby contributing to the positive externality of malaria control.

**The insufficiency of incentives:**
Though incentives to engage in malaria control exist, it is clear that incentives alone are not sufficiently abundant, clear, or aligned to motivate scaled-up and coordinated control efforts which could amount to country-level or regional elimination in endemic countries. For example, most corporate social responsibility activities from foreign firms in Mozambique are broadly focused on general development rather than narrowly targeting malaria.
There is a high degree of scepticism regarding the likelihood of near-term success of ambitious, paradigm-shifting accomplishments (ie, eradication). Scepticism goes a long way in explaining why, despite the apparent social good returns on scaled-up malaria elimination being so great (Sachs and Malaney 2002; World Health Organization 2019), investment in elimination and eradication interventions has not been great enough to achieve those paradigm shifts. In other words, enthusiasm for ambitious investment in malaria control and elimination is tempered by scepticism over the expected value of those investments, not due to doubts over whether suppressing malaria would be widely beneficial, but rather due to doubts over the collective ability to suppress malaria. In other words, It is potentially the case that those who design social corporate responsibility programs, like the researchers who participated in the Survey of Experts study, harbor a high degree of scepticism regarding the likelihood of near-term collective “success”, and therefore optimize programs to achieve returns at a rate prior to the point of diminishing returns (Murphet and Murphet 2019).

**The question of free-riding and moral hazard:**

If incentives for control exist, there must be larger phenomena at play which dissuade actors from pursuing measures sufficiently ambitious to change the paradigm from control to elimination in certain regions. This would be consistent with the “common good” interpretation and the associated “free rider” hypothesis; that is, it is entirely rational for a firm to prefer that someone else shoulder the burden of the costs of malaria control and elimination efforts, leaving the firm to benefit from those efforts without the capital costs nor risk. Alternatively, at its most perverse, it could be the case that a firm’s ambitious engagement in malaria control could be so successful that it would benefit competitors or dissuade the government from investing in the health of the firm’s employees (ie, “crowding out” of other actors in the provisioning of the public good). A similar free-rider phenomenon could also be taking place at the individual-level wherein people readily engage in those malaria control activities which are of low-cost and low-burden (such as hanging a bednet to sleep in), but prefer not to engage in those activities (despite the positive externalities) if they perceive that the direct benefit is scant. The most concrete example of “last mile” elimination: once transmission is suppressed to very low levels, the individual benefit accrued from engaging in control activities is very low, and the unit cost of those activities remains identical; despite the collective benefits being high, the low cost-benefit ratio at the individual level disincentivizes sustained or scaled control activities. This dissertation did not generate any evidence pertaining to this last point, but it is consistent with a Ghanean study in which enrollment in a health insurance plan was associated with decreased bednet usage (Yilma, van Kempen, and de Hoop 2012). It stands to reason that as individuals, firms, and countries experience lower malaria incidence, the marginal costs of prevention will increase, and the direct benefits of prevention investment will be more dispersed. The game theory involved in this scenario has been studied mathematically and theorized in regards to disease elimination (Poliomyelitis and Technical Consultative Group to the World Health Organization on the Global Eradication of Poliomyelitis 2002) as well as vaccine uptake (McKillop et al. 2019).

**Complexity as culprit:**

Tangential to macro-level scepticism, lower-level complexity is an important culprit in the hesitancy to scale-up malaria control efforts, despite abundance of the apparent benefits. Conceptualizing risk and probability are enormously difficult and oftentimes inaccurate even at the individual level (Jumbam et al. 2020; Mnyone and Mwamundela, n.d.; Forero et al. 2014). At the level of the firm, quantifying and acting on long-term, high-uncertainty assumptions built on a scarce and ever-changing evidence base is near impossible. In this sense, the reason a firm like Maragra might engage in malaria control activities with no intention of either scaling up nor down those activities’ scope in the near future would not be because they believe they have identified the *optimal* investment-in-health spending point, but rather because they are unaware of where that point is, nor of the extent to which their current activities are costly or beneficial. This is consistent with the results of the Survey of Experts paper, where complexity was highlighted as one of the main reasons why researchers doubt the feasibility of near-term eradication of malaria. Similarly, from a financial perspective, the aptness of the complexity issue resonates in study 4 (the vaccine costing systematic review) wherein it was found that the ways by and categories in which costs are counted are incompatible both across time and space.

It stands to reason that individuals, firms, and countries are not engaged in a multi-dimensional competition with each other to see who can most benefit from the others

positive externalities, but rather are simply confused by the complexity of the malaria control problem, like specialists who research it. Complexity leads to uncertainty, which in turn leads to some degree of complacence. After all, if one is not aware of or confident in the likely outcome of an activity (such as increased engagement in malaria control), it is entirely reasonable to err on the side of trusted “experts” (Finda et al. 2020), who (as shown in study 1) are themselves sceptical over the extent to which scaled-up efforts will lead to success. This dissertation shows that complexity may be an important element hindering increased engagement in malaria control activities not because it directly affects the incentives for control or elimination, but because it makes the perception of those incentives less clear. Complexity seeps into not only the costing of interventions (studies 4 and 6), the optimizing of those interventions in complex human-animal dynamic situations (study 5), the quantification of the effectiveness of those interventions (study 3), but also the estimation of the expected value of those interventions (study 1). In turn, stakeholders engaged in malaria control and elimination-related activities (such as large foreign firms) may choose to “diversify” the corporate social responsibility portfolio, weighting more heavily towards those areas which are perceived to be less complex than malaria control and are also less binary in outcome than malaria elimination.

## 10.2 Question-specific conclusions

**An abundance of opportunities**

Where do opportunities exist for enlarging the body of stakeholders and funders involved in malaria control? It is clear from the literature that there is no shortage of areas where malaria control might be scaled up all the way towards elimination, starting with vector control (Winskill et al. 2019). Beyond the incremental progress of improved vector control strategies and compounds, the finding from the Maragra sugarcane facility, that firm-administered vector control (in the form of indoor residual spraying) not only lead to significant decreases in absence but was even profitable, could lead to a qualitative jump in malaria control activity if communicated effectively to firms. That is, if some firms were already willing to engage in malaria control without the explicit knowledge of its direct economic benefits, making those firms aware that those benefits are substantial might serve to drive them towards action (while at the same time addressing the primary insight from this research – that complexity is a major impediment to incentivization).

The opportunity to scale up involvement in private sector malaria control, evidenced by the diverse landscape of large (and well-funded) foreign firms already engaging in corporate social responsibility in Mozambique (study 2), is not limited only to Mozambique, nor should it be understood only within the narrow limits of firms engaging in vector control activities to protect their workers from infection. In fact, a wide variety of areas could leverage private sector involvement ((Bennett et al. 2017)), as long as doing so does not undermine the fundamental nature of malaria control and elimination as public goods, nor unduly concentrate risk and reliance in private hands. Though study 6 focused solely on the firm at Maragra, in areas where the cost-benefit ratio of malaria control activities were not so favorable to private investment (due to differential epidemiology, spatial density, or cost structures), public-private partnerships (PPP) may offer promise (Njau et al. 2009).

Beyond the potential for an expanded role of the private sector in malaria control, other opportunities for enlarging the body of stakeholders in malaria control exist. One important

distinction between the current era of eradication and the (failed) eradication drive of the 1950s and 1960s is that technology has substantially accelerated data collection and sharing initiatives. Accordingly, the top-down approach of the bygone era is no longer necessary since local governments and initiatives can access the same body of evidence and best practices for malaria control as those administering large international programs. Incentive-wise, innovation could be accelerated if funding mechanisms were made available to those working at the local level. After all, a frequent thee in the survey of experts paper (study 1) was the need for localized solutions and innovation.

Lastly, and in line with the need for innovation, opportunity for scaling up malaria control exists by integrating it into multi-pronged programs whose objective is not solely malaria. If current experimental trials on using endectocide for the purposes of reducing malaria transmission prove successful (The Ivermectin Roadmappers 2020), integrating de-parasitizing programs with malaria control programs could lead to substantial synergies, particularly if geographically prioritized (study 5). The potential effect of these combinatory approaches is not a function solely of the drop in transmission from endectocide distribution via a reduction in the amount of non-lethal blood meal available to mosquitoes, but also the fact that the positive externality of the malaria control mechanism (healthier and larger cattle, in this case) would likely lead to adoption and promotion of the mechanism by sectors previously less incentivized to do so.

**But a long ways to go...**

What is the likelihood of and time-frame to malaria eradication? No study, however well-designed, can address this question with a high degree of certainty. Since collective reasoning has been shown to be more accurate than individual judgment in areas of high uncertainty (Hamada, Nakayama, and Saiki 2020), study 6 focuses on gauging overall researcher sentiment on the likelihood of, timeframe to, and issues associated with malaria eradication at a global scale. The results of this study suggest that malaria researchers are pessimistic regarding short-term success. This pessimism largely stems from the perceived need for innovation, complexity, and the systemic challenges of discoordination, health services systems weaknesses, lack of political will, and poverty.

**Clarity on costs are needed**

How much does malaria control cost? Studies 4 and 6 aimed to quantify both hypothetical and observed malaria control interventions, which were radically different in scope (all of Sub-Saharan Africa vs one firm) and method (an innovative future vaccine versus a very common method of vector control). The principle conclusion from study 4, in regards to costs, is that better data systems and protocols are required in order for programs to generate cost data which are comparable across space and time. The huge variance in cost per dose delivered suggests low internal validity.

Conversely, though each kind of cost was well-documented and categorized in study 6 (i.e., it had high internal validity), there is no evidence to suggest that the costs of fumigation at Maragra are generalizable to other locations or epidemiological contexts. The method we used to estimate the effect of IRS on absenteeism was highly dependent on the spatial density of workers, and likely dependent on the nature of the work performed and socioeconomic status of workers (insofar as the marginal protection from malaria control

programs is less when workers are of higher socioeconomic status, and can therefore afford to take more ambitious malaria prevention measures at the individual level).

The lack of clarity on costs, and the challenges in generalizing study-specific cost findings, add to the complex nature of the malaria control incentives problems. Though the evidence generated in study 6 regarding the relative benefits of malaria control activities leads to optimism, a great deal of further work is required in identifying the extent to which the case of Maragra is unique or universal. Regardless, clarity on costs is a prerequisite for expanding the body of stakeholders in malaria control.

**Effectiveness**

What are the effects of malaria control and elimination activities? Studies 3 and 6 provided evidence that malaria control activities have the potential to be highly effective insofar as they are met with high uptake and cooperation from the community and can be self-financing (respectively). Though neither study directly measured the vector control strategies' effectiveness in preventing malaria among those who received the interventions (ITN and IRS, respectively), both studies' findings contained elements of information which lend themselves to optimism. In rural Gambia, using a method which has been shown to de-bias responses in other contexts, it appears that bednet usage is very high. In rural Mozambique, at a sugar processing farm and facility, IRS lead to a reduction in absences significant enough to offset the costs of the program. In other words, both the bednet distribution program in Gambia and the fumigation program at the Mozambican firm were *effective* at least some of their intended objectives (providing the population with a protective measure it will use and reducing the incidence of absenteeism among workers).

**Doubts about the data**

However, in both of the aforementioned cases, legitimate doubts can be raised. In study 3, the method used (list randomization) had no mechanism for validation; in study 6, the endpoint used (absenteeism) was not validated by the biological mechanism (evidence of infection); that said, it is plausible that the mechanism for reducing absence is both biological (preventing infection in workers) and social (preventing infection in workers' family members, who the workers would then be compelled to provide care for instead of working). In either case, since IRS cannot be assumed to be fully random, there is no way to parse out the role of selection bias in accounting for differential absenteeism rates among members of different households (for example, there is no objective data available on IRS refusals). This leads to the final research question addressed by this dissertation: To what extent can we rely on the data generated by malaria-related research? Study 3 offers a novel, but ultimately unsatisfying (insofar as it lacks validation), glimpse at how what we observe might not truly reflect what occurs. Study 5 relies on data curated from a myriad of sources on livestock density and parasite prevalence. Though these data may be best in kind (and more rigorously and systematically collected than at any point previously), this does not mean that they are correct. On the contrary, it could be the case that the *unobserved* data are precisely those data points which are most important to malaria control (in the sense that the most isolated areas will likely serve in future as the last blood reservoir of the malaria parasite prior to eradication).

Study 6 is a unique case in that it uses firm-generated administrative data, which has the positive attribute of having a high standard for accuracy for economic reasons. That is,

beyond the research value, a firm knowing when, where and how it spends its resources is unto itself a valuable investment. Accordingly, Maragra (like many firms) has sophisticated data management platforms for tracking human resources and activities. Though the objective of these platforms is not research per se, the platform's robustness (relative to those data collection tools build ad-hoc, often with low budgets, for the specific purpose of collecting research data) is a strength. In this sense, in response to the question on the extent to which we can trust data generated by malaria-related research, study 6 offers a high degree of reliability. Accordingly, the conclusions from study 6 regarding the potential profitability of malaria control activities at the firm level, should be considered robust; though study 3 has the advantage of being experimental in nature, it uses an unvalidated endpoint; studies 4 and 5 have the limitation of a reliance on diverse and discrepant data sources; and studies 1 and 2 have the limitation of combining a mix of grey and white literature (study 2) and self-reporting only (study 1).

So, can we rely on the data we collect? Yes, but the degree of our reliance should be proportionate to the robustness of the methods and sources used. In the case of this dissertation, the most significant finding (that malaria control may be profitable in some cases) has the good fortune of stemming from the study with the most robust data.

## 10.3 Overall conclusions

1. Incentives for malaria control exist for private organizations. A firm engaging in malaria control activities can expect a positive short-term return on the investment, even if excluding all non-financial benefits in the quantification of the return. Beyond financial benefit, firms benefit in terms of public relations from engaging in corporate social responsibilities, including malaria control.
2. Incentives for malaria control exist for individuals. Using methods meant to minimize social desirability bias, usage of ITNs by rural Gambians was estimated to be very high, suggesting that people who are on the recipient end of malaria control interventions perceive them as sufficiently valuable so as to engage in them.
3. Though incentives for control exist, individual and organizational actors are not, or do not perceive to be, sufficiently incentivized to engage in the degree of malaria control which could lead to area-wise elimination or worldwide eradication, as evidenced by a regression in progress in recent years. The insufficiency of incentives is exasperated by both (a) significant scepticism, and even pessimism, regarding the likelihood of near-term paradigm shifts (elimination) , (b) the perception of complexity in regards to the critical path towards and respective roles for achieving those shifts, and (c) an overall unfamiliarity with the core study-generated data which could inform both key performance indicators of malaria control and effectiveness evaluations.
4. Given the current insufficiency of status quo malaria control methods to accelerate progress, innovation is needed. Technical innovation is fundamental in order to outpace parasite and vector resistance, but other forms of innovation may be complementary, including both widening the body of stakeholders involved in coordinated malaria control efforts as well as enlisting combinatorial methods in which the benefits to those who partake go beyond just malaria.
5. The cost of malaria control is less than the cost of not controlling malaria, though a lack of standardized, transparent, comparable data on the costs and economic

benefits of malaria control make it so that decision-makers have to choose from a myriad of development interventions in what is essentially an opaque-pricing market, resulting in potential under-investment in malaria.

## 10.4 Limitations

This dissertation is not without significant limitations. The survey of malaria experts (study 1) included only academic researchers, who may be less familiar with the “real-world” challenges of malaria control than those who are purely devoted to operations. Sample size was large, but response rates were low. The proxy measurement for research impact (total number of citations) is biased in ways that go without saying. The pool of respondents was slightly different demographically than the group of researchers who rejected the invitation to participate, and though estimates were de-biased, there exists no technique for validating the quality of the de-biasing. In addition to the potential fallacies regarding how humans perceive future probabilities, the study also has the limitation of simply not delving into much depth in regards to respondents’ specific experiences, geographies, or reasons for participation. In other words, there was no mechanism (such as confirmatory questions, follow-up discussion, member checks) by which to probe further into survey responses. The resulting analysis of free text responses was therefore in some ways more similar to a document analysis than a qualitative research undertaking.

The analysis of foreign direct investment and corporate social responsibility in the malaria landscape of Mozambique (study 2) shared a limitation with study 1 in regards to generalizability: the limited use research databases. Study 1 used only PubMed to retrieve authors and their publication-related metadata, and Study 2 used PubMed and EBSCOhost. In both cases, this meant not detecting researchers who publish in journals indexed elsewhere.

The study of bednet usage among Gambians (study 3) utilized a novel technique which has never been validated. Though a reasonable reading of the results points to the technique’s utility, the internal validity of the study is questionable since biases unbeknownst to the researcher may have crept into the data elicitation method. Additionally, the study’s external reliability may be low given that it took place in an area with a great deal of prior health research. The sample size was relatively small, precluding any meaningful analysis of characteristics associated with bednet usage, and the pattern of response suggests that perhaps the list randomization method might result in a certain degree of “centering” responses to non-extremes in certain populations.

Estimating the costs of a hypothetical malaria vaccine roll-out in Sub-Saharan Africa based on existing vaccine programs (study 4) was an endeavor bound to meet certain limitations. Among them, like study 1, this analysis used the PubMed database, therefore overlooking gray literature. Additionally, incremental costs were found to be highly contingent on local capacity, making variability high (and external generalizability low). Finally, we were unable to perform financial versus economic analyses, due to the non-standardized nature of our data.

Mapping opportunities for endectocide for malaria control (study 5) had the limitation of relying purely on ecological-level data, with no incorporation whatsoever as to what was

feasible operationally, economically, or culturally. The analysis also made no attempt to quantify the environmental costs of a mass endectocide for malaria campaign, nor did it explore opportunity costs. Finally, the analysis was largely speculative, and did not fit its findings into the larger malaria eradication global campaign.

The analysis of absenteeism among sugarcane workers (study 6) assumed a linear decay in IRS effectiveness, when in reality it is almost certainly non-linear (but unknown). The study also assumed that absences correlated directly with lost productivity. Though sample size was very large, the degree to which results are externally generalizable is questionable since much of the effect of IRS (per our model) depends on the timing of fumigations and precipitation, as well as the geographic density of workers' residences.

## 10.5 Further research

This dissertation opens the door to several lines of research which should be carried out in the short-term. The finding that malaria researchers are more pessimistic about the prospects of eradication than their institutions merits deeper investigation, specifically in regards to the potential incentives researchers might have for not speaking their minds freely (or, conversely, the incentives institutions face to generate optimistic communication in order to attract funding). By the same token, the study's approach should be expanded to other stakeholders in the malaria-control community, outside of PhD-level academic researchers, especially those with on-the-ground knowledge and operational experience.

The results of the study of bednet usage among Gambians leads to questions both about (a) the subject area itself and (b) the methodology. In regards to the former, more research is needed on the "decay" in usage of bednets over time. Snapshot, cross-sectional estimates are useful, but insufficient for predicting when a campaign would be most useful and to whom it should target. The list randomization methodology is promising, but requires further validation before it can be used as a reliable indicator at scale. Since human-observation in the household would constitute too significant an invasion of privacy, validation study of list randomization could use direct observation via non-invasive sensors.

In order to improve estimates on the costs of vaccine programs, a standardized set of guidelines for reporting these types of costs is urgently needed. A design-thinking approach should employ mixed-methods data collection of those who administer vaccine programs in Sub-Saharan Africa so as to elicit, qualitatively, their perspectives on costs. Following the qualitative phase, a universal categorization of costs should be designed, and quantitative cost data should be collected using it. To determine how robust cost types are to the categorizations, multiple people at each participating study site should categorize the costs themselves so as to allow for the posterior comparison of costs which are commonly miscategorized.

Finally, and perhaps most impactfully, further research is needed to assess the generalizability of the important finding that a private firm investing in reducing malaria among workers can pay for itself. If validated in other sites (with their own unique combination of worker types, epidemiological and meteorological conditions, geographic density, etc.), the finding that malaria control can be profitable could have important implications for the role that the private sector plays in the march towards eradication.

## 10.6 Reflection

**All the conditions are right; so why do we keep getting it wrong?**
From a purely technical perspective, conditions are ripe in many locations for malaria elimination. Though not highly effective, one-dose vaccine yet exists, many other factors are favorable for malaria control: knowledge on the parasite is certainly sufficient: the scientific and public health communities know more, and share more, in regards to malaria than at any time in history. Preventive measures are advanced and effective: population-level interventions like larviciding, outdoor space spraying, and water management are feasible even in remote areas, and individual-level prevention measures, ranging from indoor residual spraying to intermittent preventive treatment and insecticide-treated nets, have never been so widespread. These factors, combined with rapid economic development in recent decades in the most malaria-stricken areas of the world, might suggest that even eradication is not unfeasible[1].

Given all the apparently facilitating factors for reducing the burden of malaria worldwide, the obvious question arises: why has eradication not occurred? And even more worryingly, why has elimination progress in recent years stalled, with virtually the same number of cases in 2018 (228 million) as in 2010 (251 million) (World Health Organization 2019)? If all the conditions are *right* for large leaps forward in malaria control, then what are we doing *wrong*?

The answers to these questions are not immediately clear. What is clear, however, is that a deeper examination of the prerequisite conditions, facilitating factors, barriers, and incentives for control, elimination, and eradication needs to take place, using novel methods to try to understand why what *should* work ,hasn't worked. But this examination must go beyond the limits of one discipline, or the normal confines of what is considered to be the "health sector".

The structure may appear somewhat disjointed. That's because it is. As is the case with many doctoral students, my original vision for this PhD did not coincide neatly with reality, nor with what I considered to be the most pressing research needs as I learned more about the field. Unlike most doctoral students, however, the *transdisciplinary* nature of my program granted me sufficient intellectual liberty to *pivot* as I incorporated new knowledge, and new collaborations, into my research. If I were to summarize this process, I would call it "unintentional emergent design".

Whereas most doctoral theses go from the general to the specific, the flow of work in mine was backwards: from the specific to the general. I started with concrete, tangible, quantifiable research questions about specific projects and interventions. But the answers from each study simply provoked more questions, each of them progressively further from those domains where I felt most comfortable. If malaria control activities were profitable, why weren't more firms doing them? If more firms did them, how could their efforts be coordinated towards elimination? If massive, coordinate elimination efforts don't succeed in eliminating malaria, what non-traditional methods might do the trick? Can malaria elimination eradicate poverty, or is the causal pathway backwards? Is eradication even possible? These

[1] "Eradication" is defined by the World Health Organization as the "permanent reduction to zero of the worldwide incidence of infection caused by human malaria parasites as a result of deliberate activities".

are some of the questions which were not present in my original research plan, but ultimately came to define the studies I undertook.

On a personal level too, my PhD journey has been one from the specific to the general. When I began in 2016, I had a more firm concept of my own identity and role in the world of public health. I saw myself as an epidemiologist and data scientist, with a passion for numbers, disease control, and statistical analysis. I had just finished 3 years working in disease control at the Florida Department of Health, and I was ready to apply what I had learned there to the economics of malaria. Put simply, I thought of myself as the “subject” and the PhD as the “object”; that is, I was going to do something *to* the research.

What I didn’t realize, going in, was that the research itself was going to do something to me. The transdisciplinary method, which at the outset I had considered a minor annoyance or formality, was more powerful than I anticipated. Its *iterative* approach to knowledge acquisition - asking, re-asking, incorporating new viewpoints, generating new questions based on intermediary learnings - contrasted sharply with my much more *protocolized* mindset towards research, partly a vestige of my previous research and work experience, and partly a vestige of my own personality. By being forced to wrestle with research questions that emerged *during* (rather than simply before) the research process was underway, I was also obligated to embrace research *methods* that I had not originally set out to explore, such as bias-reducing interview techniques and qualitative data analysis. Ultimately, the journey broke down my previous constructed identity of my role in the public health and research landscape. In learning that the methods I felt most comfortable with were insufficient to answer the questions I found to be most pressing, I also learned that I needed to delve into new methods, seek new partners, and ask new questions. I describe this personal journey as one from the *specific* to the *general* because it has helped me escape from the restrictive (and reductionist) mindset I had at the beginning of this process, and has pushed me towards areas of knowledge-acquisition with which I previously felt a much greater deal of discomfort.

Two kinds of knowledge emerge from the research process: (1) the *specific* discoveries generated from the study itself (which are transferable - via publications, code repositories, presentations, and posters - to others), and (2) the *general* knowledge gained from the *experience* of conducting the research. The latter requires more intentionality and reflection (one of the advantages of the transdisciplinary approach), is harder to demonstrate publicly, and is far more difficult to transfer to others. But its effects are real. At the crossroads of epidemiology and economics, public health and private firms, lofty goals and concrete data endpoints, is a world unto itself: the world of malaria. Navigating this world successfully (and by this I mean, eventually, getting to eradication) will require re-inventing the way we think about malaria; and this re-invention requires a crossing of disciplines, a leap out of the confines of the public and academic sectors, and a hefty dose of self-criticism and doubt. In other words, it requires a degree of re-inventing one’s self. For me, this PhD was a start at exactly that.

## 10.7 Concluding remarks

Malaria can be both prevented and cured. And technically speaking, it can be eliminated in areas, and therefore eradicated globally. Why, then, do these solvable problems go unsolved?

My ingoing hypothesis with this research was that there existed an *insufficiency* of incentives for individuals and firms to invest meaningfully in eradication-related measures. However, the findings of these studies challenged that hypothesis while also complicating it somewhat. The theory that incentives were insufficient for individuals to take malaria control measures was roundly shot down by the finding that nearly 100% of Gambians sleep under a mosquito net. And insufficiency of incentives also did not explain the vast landscape of corporate social responsibility geared at malaria control. Finally, in the qualitative analysis of the hundreds of comments from malaria researchers regarding the obstacles to eradication, nearly none pointed towards incentives, instead highlighting technical, political, and biological challenges.

Insufficiency of incentives certainly plays an important role in the case of some measures not being implemented, but it is clearly not the only role. On the contrary, if there is any lesson to be taken from the study of the sugarcane plantation, it is that some firms are willing to carry out malaria control activities despite an *ignorance* of the incentives (that is, not have quantified whether the program was cost-generating or revenue-generating). Complexity, not a lack of incentives, is the driving factor here.

The economics of malaria control clearly go beyond simple incentives. Accordingly, scaling up malaria control in endemic countries (a necessary prerequisite to eradication) will require more than just incentivization, but also:

- Alignment (i.e., foreign firms working in coordination with the government so that corporate social responsibility activities are not misdirected);
- Clear communication (i.e., researchers speaking openly about their pessimism regarding timelines espoused by the institutions which often fund them);
- Organization (i.e., data around disease control activities like vaccine campaigns being standardized, readily shared, and openly audited for quality assurance);
- Innovation (i.e., working across disciplines and sectors to experiment rapidly with new methods and measures).

# Bibliography


Abel, T. 2008. “Cultural Capital and Social Inequality in Health.” *Journal of Epidemiology & Community Health*. https://doi.org/10.1136/jech.2007.066159.

Aguirre, A. Alonso, A. Alonso Aguirre, Niladri Basu, Laura H. Kahn, Xenia K. Morin, Pierre Echaubard, Bruce A. Wilcox, and Val R. Beasley. 2019. “Transdisciplinary and Social-Ecological Health frameworks—Novel Approaches to Emerging Parasitic and Vector-Borne Diseases.” *Parasite Epidemiology and Control*. https://doi.org/10.1016/j.parepi.2019.e00084.

Alonso, Pedro L., Graham Brown, Myriam Arevalo-Herrera, Fred Binka, Chetan Chitnis, Frank Collins, Ogobara K. Doumbo, et al. 2011. “A Research Agenda to Underpin Malaria Eradication.” *PLoS Medicine* 8 (1): e1000406.

Anderson, D. E., and A. Laveran. 1893. “THE HÆMATOZOA OF MALARIA.” *The Lancet*. https://doi.org/10.1016/s0140-6736(01)45658-3.

Bennett, Adam, Anton L. V. Avanceña, Jennifer Wegbreit, Chris Cotter, Kathryn Roberts, and Roly Gosling. 2017. “Engaging the Private Sector in Malaria Surveillance: A Review of Strategies and Recommendations for Elimination Settings.” *Malaria Journal* 16 (1): 1–19.

Bergstrom, T., L. Blume, and H. Varian. 1986. “On the Private Provision of Public Goods.” *Journal of Public Economics* 29 (1): 25–49.

Bronfenbrenner, Urie. 2000. “Ecological Systems Theory.” *Encyclopedia of Psychology, Vol. 3.* https://doi.org/10.1037/10518-046.

Cavallo, D. 2000. “Emergent Design and Learning Environments: Building on Indigenous Knowledge.” *IBM Systems Journal*. https://doi.org/10.1147/sj.393.0768.

CDC-Centers for Disease Control, and Prevention. 2009. “CDC - Malaria - About Malaria - History - The Panama Canal,” February. https://www.cdc.gov/malaria/about/history/panama_canal.html.

Daniels, W. B. 1950. “Albert Freeman Africanus King (1841-1914); His Theory as to the Transmission of Malaria by Mosquitoes.” *The Medical Annals of the District of Columbia* 19 (9): 499–505; passim.

Drury, William H. 1963. “Silent Spring Rachel Carson.” *The Auk*. https://doi.org/10.2307/4082572.

Eriksson, Lina. 2011. “What Is Rational Choice Theory?” *Rational Choice Theory*. https://doi.org/10.1007/978-0-230-34379-5_2.

Feachem, Richard G. A., Ingrid Chen, Omar Akbari, Amelia Bertozzi-Villa, Samir Bhatt, Fred Binka, Maciej F. Boni, et al. 2019. “Malaria Eradication within a Generation: Ambitious, Achievable, and Necessary.” *The Lancet* 394 (10203): 1056–1112.

Finda, Marceline F., Nicola Christofides, Javier Lezaun, Brian Tarimo, Prosper Chaki, Ann H. Kelly, Ntuli Kapologwe, Paul Kazyoba, Basiliana Emidi, and Fredros O. Okumu. 2020. “Opinions of Key Stakeholders on Alternative Interventions for Malaria Control and Elimination in Tanzania.” *Malaria Journal* 19. https://doi.org/10.1186/s12936-020-03239-z.

Forero, David A., Pablo E. Chaparro, Andres F. Vallejo, Yoldy Benavides, Juan B. Gutiérrez, Myriam Arévalo-Herrera, and Sócrates Herrera. 2014. “Knowledge, Attitudes and Practices of Malaria in Colombia.” *Malaria Journal*. https://doi.org/10.1186/1475-2875-13-165.

Golden, Shelley D., and Jo Anne L. Earp. 2012. “Social Ecological Approaches to Individuals and Their Contexts: Twenty Years of Health Education & Behavior Health Promotion Interventions.” *Health Education & Behavior: The Official Publication of the Society for Public Health Education* 39 (3): 364–72.

Grossman, Michael. 1972. “On the Concept of Health Capital and the Demand for Health.” *Journal of Political Economy*. https://doi.org/10.1086/259880.

Gross, Michael. 2003. “Gates Foots a Malaria Bill.” *Current Biology*. https://doi.org/10.1016/j.cub.2003.10.008.
Gulis, Gabriel, and Yoshihisa Fujino. 2015. “Epidemiology, Population Health, and Health Impact Assessment.” *Journal of Epidemiology*. https://doi.org/10.2188/jea.je20140212.
Hamada, Daisuke, Masataka Nakayama, and Jun Saiki. 2020. “Wisdom of Crowds and Collective Decision-Making in a Survival Situation with Complex Information Integration.” *Cognitive Research: Principles and Implications* 5 (December). https://doi.org/10.1186/s41235-020-00248-z.
Hay, Simon I., Carlos A. Guerra, Andrew J. Tatem, Abdisalan M. Noor, and Robert W. Snow. 2004. “The Global Distribution and Population at Risk of Malaria: Past, Present, and Future.” *The Lancet Infectious Diseases* 4 (6): 327–36.
Hempelmann, Ernst, and Kristine Krafts. 2013. “Bad Air, Amulets and Mosquitoes: 2,000 Years of Changing Perspectives on Malaria.” *Malaria Journal* 12 (July): 232.
Hippocrates. 2007. *On Airs, Waters and Places*. Library of Alexandria.
Institute of Medicine, Board on Global Health, and Committee on the Economics of Antimalarial Drugs. 2004. *Saving Lives, Buying Time: Economics of Malaria Drugs in an Age of Resistance*. National Academies Press.
“Is Malaria Eradication Possible?” 2007. *The Lancet* 370 (9597): 1459.
Johnson, Charles Earl, and Medical Society of the State of North Carolina. 1851. *An Address before the Medical Society of North Carolina: At Its Second Annual Meeting, in Raleigh, May 1851*.
Jumbam, Desmond T., Jennifer C. Stevenson, Japhet Matoba, John P. Grieco, Lacey N. Ahern, Busiku Hamainza, Chadwick H. Sikaala, et al. 2020. “Knowledge, Attitudes and Practices Assessment of Malaria Interventions in Rural Zambia.” *BMC Public Health* 20 (1): 216.
Killeen, Gerry F., Ulrike Fillinger, Ibrahim Kiche, Louis C. Gouagna, and Bart G. J. Knols. 2002. “Eradication of Anopheles Gambiae from Brazil: Lessons for Malaria Control in Africa?” *The Lancet Infectious Diseases* 2 (10): 618–27.
Knapp, R. n.d. “Wholesome Design for Wicked Problems | Public Sphere Project — Liberating Voices Pattern Language.” Accessed April 19, 2020. http://publicsphereproject.org/content/wholesome-design-wicked-problems.
Lancet, The, and The Lancet. 2011. “Malaria: Control vs Elimination vs Eradication.” *The Lancet*. https://doi.org/10.1016/s0140-6736(11)61489-x.
“Malaria: A Brief History.” 2016. *Spatial Agent-Based Simulation Modeling in Public Health*. https://doi.org/10.1002/9781118964385.ch2.
“Malaria Consortium.” n.d. Accessed April 19, 2020. https://www.malariaconsortium.org:443/news-centre/lessons-from-the-past-can-malaria-ever-be-eradicated.htm.
McKillop, Caitlin N., Tammy Leonard, Sandi L. Pruitt, and Jasmin A. Tiro. 2019. “Do Traditional Economic Theories of Free Riding Behavior Explain Spatial Clustering of HPV Vaccine Uptake?” *SSM - Population Health* 8 (August): 100421.
Mendis, Kamini, Aafje Rietveld, Marian Warsame, Andrea Bosman, Brian Greenwood, and Walther H. Wernsdorfer. 2009. “From Malaria Control to Eradication: The WHO Perspective.” *Tropical Medicine & International Health: TM & IH* 14 (7): 802–9.
Mnyone, Ladslaus Laurent, and Baraka Mwamundela. n.d. “Knowledge, Attitudes, Practices and Risk Factors about Malaria in High Endemic Rural Eastern Tanzania.” https://doi.org/10.21203/rs.3.rs-41901/v1.
Murphet, Julian, and Julian Murphet. 2019. “The Law of Diminishing Returns.” *Todd Solondz*. https://doi.org/10.5622/illinois/9780252042768.003.0001.
Njau, R. J., D. de Savigny, L. Gilson, E. Mwageni, and F. W. Mosha. 2009. “Implementation of an Insecticide-Treated Net Subsidy Scheme under a Public-Private Partnership for Malaria Control in Tanzania--Challenges in Implementation.” *Malaria Journal* 8 (August). https://doi.org/10.1186/1475-2875-8-201.
Olson, Mancur. 2009. *THE LOGIC OF COLLECTIVE ACTION*. Harvard University Press.
Pohl, Christian, Bernhard Truffer, and Gertrude Hirsch-Hadorn. 2017. “Addressing Wicked

Problems through Transdisciplinary Research." *Oxford Handbooks Online*. https://doi.org/10.1093/oxfordhb/9780198733522.013.26.
Poliomyelitis, Technical Consultative Group to The World Health Organization on The Global Eradication of, and Technical Consultative Group to the World Health Organization on the Global Eradication of Poliomyelitis. 2002. "'Endgame' Issues for the Global Polio Eradication Initiative." *Clinical Infectious Diseases*. https://doi.org/10.1086/338262.
Roberts, N. C. 2000. "Wicked Problems and Network Approaches to Resolution." *International Public Management Review*. http://journals.sfu.ca/ipmr/index.php/ipmr/article/download/175/175.
Sachs, Jeffrey, and Pia Malaney. 2002. "The Economic and Social Burden of Malaria." *Nature* 415 (6872): 680–85.
Schneider-Kamp, Anna. 2020. "Health Capital: Toward a Conceptual Framework for Understanding the Construction of Individual Health." *Social Theory & Health*. https://doi.org/10.1057/s41285-020-00145-x.
Surhone, Lambert M., Miriam T. Timpledon, and Susan F. Marseken. 2010. *Wicked Problem: C. West Churchman, Horst Rittel, Melvin M. Webber, Business Decision Mapping, Critical Thinking*.
The Ivermectin Roadmappers. 2020. "A Roadmap for the Development of Ivermectin as a Complementary Malaria Vector Control Tool." *The American Journal of Tropical Medicine and Hygiene* 102 (2 Suppl): 3.
"The Path between the Seas: The Creation of the Panama Canal, 1870-1914." n.d. *The SHAFR Guide Online*. https://doi.org/10.1163/2468-1733_shafr_sim080190361.
Trape, J. F., G. Pison, M. P. Preziosi, C. Enel, A. Desgrées du Loû, V. Delaunay, B. Samb, E. Lagarde, J. F. Molez, and F. Simondon. 1998. "Impact of Chloroquine Resistance on Malaria Mortality." *Comptes Rendus de l'Academie Des Sciences. Serie III, Sciences de La Vie* 321 (8): 689–97.
Utzinger, Jürg, Yesim Tozan, Fadi Doumani, and Burton H. Singer. 2002. "The Economic Payoffs of Integrated Malaria Control in the Zambian Copperbelt between 1930 and 1950." *Tropical Medicine & International Health: TM & IH* 7 (8): 657–77.
Ward, Michael, and Gordon Harrison. 1979. "Mosquitoes, Malaria and Man: A History of the Hostilities Since 1880." *The Geographical Journal*. https://doi.org/10.2307/634432.
Watson, M. 1908. "EXPERIMENTS TOWARDS THE PREVENTION OF MALARIA IN THE FEDERATED MALAY STATES." *British Medical Journal* 1 (2461): 499–500.
Winskill, Peter, Patrick G. Walker, Richard E. Cibulskis, and Azra C. Ghani. 2019. "Prioritizing the Scale-up of Interventions for Malaria Control and Elimination." *Malaria Journal*. https://doi.org/10.1186/s12936-019-2755-5.
World Health Organization. 2019. "Malaria Eradication: Benefits, Future Scenarios and Feasibility: Executive Summary of the Report of the WHO Strategic Advisory Group on Malaria Eradication." World Health Organization. https://www.who.int/publications-detail/strategic-advisory-group-malaria-eradication-executive-summary.
Yilma, Zelalem, Luuk van Kempen, and Thomas de Hoop. 2012. "A Perverse `net' Effect? Health Insurance and Ex-Ante Moral Hazard in Ghana." *Social Science & Medicine* 75 (1): 138–47.